EXTRAGALACTIC H II REGIONS IN THE UV:

IMPLICATIONS FOR PRIMEVAL GALAXIES AND QUASARS*

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ABSTRACT

Three extragalactic regions of rapid star formation with redshifts great enough to separate the Lα region from geocoronal Lα have been observed with the IVE satellite. Only the low metal abundance object had detectable Lα emission. Lα is therefore expected to be weak or absent in collapsed primeval galaxies. The detected object has a Lα/Hβ ratio identical to that of quasars.

I. INTRODUCTION

Theoretical studies of primeval galaxies or PGs (Partridge and Peebles 1967; Meier 1976; Sunyaev, Tinsley, and Meier 1978, hereinafter STM; Shull and Silk 1979) indicate that redshifts will be high ($z > 3$) and that ultraviolet continuum and lines will be strong. Hence, beside providing information about the physics of H II regions themselves, ultraviolet observations of nearby regions of rapid star formation can also suggest how a young galaxy will look to observers when one is found and how it will differ from a quasar of a similar redshift. STM predicted that C IV 1550 and Si IV will be absent because of low ionizing fluxes, but that Lα will be strong. However, the Lα line is notorious for not following theoretical predictions in quasars (Baldwin 1977; Davidsen, Hartig, and Fastic 1977). Hence a study of the Lα region in H II regions may also shed light on the quasar problem.

II. OBJECTS AND OBSERVATIONS

To mimic the effects of observing an integrated stellar population, as would be the case for a PG, only H II regions (or complexes thereof) of small angular size, and hance at considerable distance, were observed. The bluest and brightest candidates were chosen from lists of Markarian galaxies (Huchra 1977 and references therein), narrow emission line objects from the UK Schmidt survey, and large H II regions in external galaxies (Searle 1971). A set of eight objects were observed with the IUE satellite with the large aperture and low dispersion in both long and short wavelength cameras. Complete spectra of all objects will be presented elsewhere (Meier and Terlevich 1980).

Three of these objects had redshifts high enough to separate the Lα region from the strong geocoronal Lα feature. MKN 12 ($z = 0.014$) is a large collection of H II regions in an Sc galaxy; 0842 + 163 ($z = 0.052$) is a compact Zwicky-type object from the UK Schmidt survey with a semi-stellar core and a wisp of material extending from the object; 1543 + 091 ($z = 0.036$) is another UK Schmidt compact with a nearly stellar image. Table 1 summarizes the optical data on these objects. In all three objects the widths of the optical lines are less than 150 km s^{-1}. In the short wavelength camera MKN 12 was exposed twice (30 min and 97 min), 0842 + 163 once (325 min), and 1543 + 091 twice (90 min and 352 min). The ESSR data were reduced at Caltech in the manner of Oke and Zimmerman (1979). The spectra from the longer exposures are plotted in Figure 1.

III. RESULTS

The results of the UV observations are summarized in Table 2. As expected the C IV and Si IV features are absent in all three objects. In the Lα and the continuum strength there appears to be an inverse correlation between metal abundance and strength of the UV feature. Only 1543 + 091 has a relatively strong continuum and has a detected Lα line; the latter has a strength 1/8 that expected from recombination theory and the Hβ strength. (This detection, incidentally, seems to be the first detection of Lα emission in an extrasolar source beside a quasar or quasar-like object.) This ratio of Lα/Hβ $\sim$ 4 is identical to all objects observed so far except the narrow line regions of 3C 390.3 (Ferland et al. 1979) and (Green, private communication) which have Lα/Hβ $\sim$ 40. The two separate exposures, taken on different nights, both show the same $L\alpha$ strength.

IV. DISCUSSION

The most plausible explanation for the inverse correlation of UV features with metal abundance is dust. The more metals there are the greater probability that interstellar dust exists in the object. If τ_D is the dust optical depth at 1216 Å in the absence of hydrogen and $\tau_{L\alpha}$ is the $L\alpha$ depth in the absence of dust, then the total optical depth to dust in the $L\alpha$ line is

$$\tau_{DL\alpha} \approx (\tau_{L\alpha}\,\tau_D)^{1/2} \qquad (1)$$

much greater than τ_D if $\tau_{L\alpha} \gg 1$. In view of the efficiency of this process it is likely that in H II regions $L\alpha$ emission will be strong only with very little or no dust and non-existent otherwise. Dust can also qualitatively explain the weaker UV continuum relative to the optical in the high Z objects, although some of this may be due to the presence of an old stellar population in these objects and the lack thereof in 1543 + 091 is just that predicted for a dust-free young object ($\sim 10^8$ yr old) and a Salpeter mass function (Meier 1976; STM).

Understanding why the $L\alpha$ strength in 1543 + 091 is so low, however, is much more difficult. There are several possible explanations, none of which seem totally satisfactory. 1) A minute amount of dust exists in the object yielding the $\tau_{DL\alpha} \sim 2$ needed. That this results in exactly the same $L\alpha/H\beta$ ratio found in quasars seems rather fortuitous. 2) All nebulae, for some reason, have $L\alpha/H\beta \sim 4$. This would conflict the Ferland et al. and Green results. 3) The clouds in 1543 + 091 are much denser than normal H II regions, yielding conditions similar to those in quasars but with a velocity of dispersion typical of galaxies. The results of Canfield and Puetter (1980) may then be applicable. One would then have to explain why the clouds in this object are so dense. 4) 1543 + 091 is unrelated to galactic H II regions: either it is not typical of extragalactic H II regions or isolated extragalactic and galactic H II regions are quite different. It would be very desirable to observe another low Z object; unfortunately I Zw 18 ($Z = 1/55\ Z_\odot$) has too small a redshift (see Meier and Terlevich 1980).

V. IMPLICATIONS FOR NORMAL H II REGIONS, PRIMEVAL GALAXIES, AND QUASARS

Normal galactic H II regions have high metal abundances implying that, in addition to the absence of C IV, Si IV, one would expect no Lα emission. Hence, it appears that H II regions, while characterized by strong lines and weak continuum in the optical are virtually featureless continuum sources in the ultraviolet.

These results also have important implications for the search for primeval galaxies. Standard models of galaxy collapse and star formation (Larson 1974; Kaufmann 1975) predict two stages of galaxy formation: 1) an extended phase ($z \sim 10 - 30$) before collapse and 2) a collapsed phase ($z \sim 2 - 16$) where the luminosity reaches its peak. In the former the metal abundance will be low, but in the latter it will be solar or nearly so due to the many enrichment times (10^{6-7} yr) during collapse (10^{8-9} yr). Based on the above we thus conclude that the standard collapsed primeval galaxies (1" - 2" images) will have UV continuum weaker than predicted by dust-free models and most likely no Lα emission. The extended (10" - 30") phase is likely to be dust-free and hance relatively strong in the UV and Lα. However, owing to its higher redshift, lower star formation rate, and extended image, it will have a very low surface brightness (> 30 m arcsec^{-2}). In addition, the Lyman limit will be redshifted out of the optical, putting what flux there is in the infrared where detectability becomes a problem.

The most promising methods for detecting PGs at present seem to involve either the redshifted optical lines of [O II], [O III], Hα, and Hβ or the redshifted far IR continuum emitted by the dust (see Kaufmann 1976). Partridge (private communication) suggests looking for fluctuations in the microwave background at high frequency where the black body exponential cut-off occurs. Primeval galaxies with their intense ((I)/I $\sim$ 1) small images would produce a significantly different fluctuation spectrum from the canonical protogalaxies usually sought with extended weak ((I)/I $\sim$ 10) fluctuations. Most of these will probably require some improvements in the current state of IR or microwave technology.

For the more general problem of studying galactic evolution at early epochs, optical efforts in galaxy counts to very faint magnitudes continues to be the best approach.

These observations also have implications for QSOs. First the dust hypothesis for the anamolous Lα/Hβ ratios apparently is inadequate. The process is so efficient in destroying Lα that it is unlikely to produce the same ratio in so many quasars. Second, if the ratio in 1543 + 091 is not a fortuitous value, then the process producing the ratio is very universal indeed, operating in this object as well as QSOs and the sun (Zirin 1978).

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TABLE 1

OPTICAL DATA

Object	z	$Z/Z_{\odot}$	$\nu f\nu[5360Å(1+z)]^{*}$	$F(H\beta)^{*}$	$F(H\alpha)$
MKN 12	0.014	1/3	1.3×10^{-10} ($m_V = 13$)	1.8×10^{-13}	----
0842+163	0.052	1	2.1×10^{-11}	1.3×10^{-13}	3.7×10^{-13}
1543+091	0.036	1/16	5.9×10^{-13}	6.5×10^{-14}	2.1×10^{-13}

*erg cm^{-2} s^{-1}

TABLE 2

UV RESULTS†

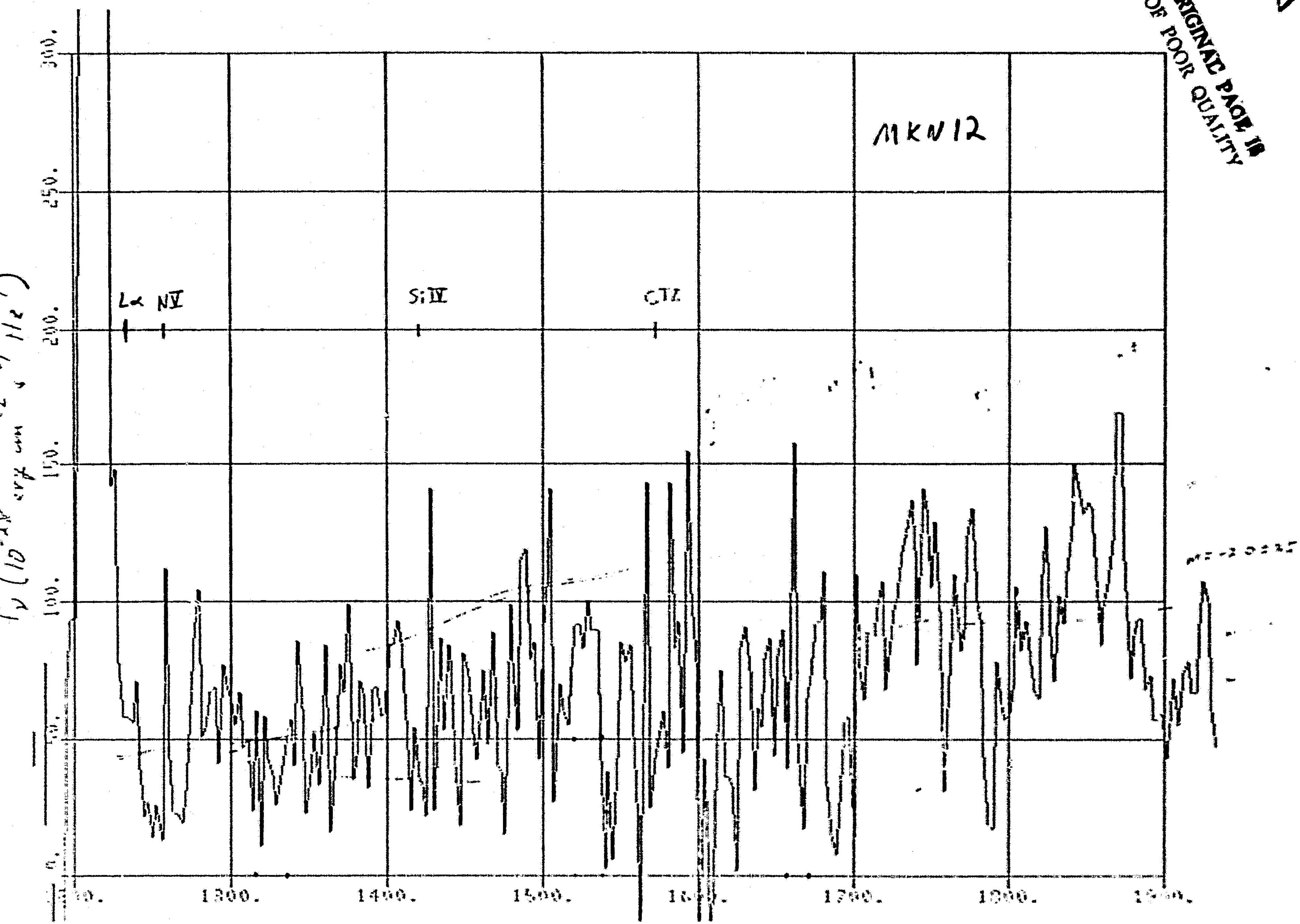
Object	F(cIV)*	F(SiIV)*	F(Lα)*	F(Lα)/F(Hβ)	$\nu f\nu$[1300Å(1+z)]*	$\nu f\nu(1300)$ / $\nu f\nu(5360)$
MKN 12	$< 4.2\times10^{-14}$	$< 3.2\times10^{-14}$	$< 4.7\times10^{-14}$	< 0.26	1.14×10^{-11}	> 0.09
0842+163	$< 1.6\times10^{-14}$	$< 1.8\times10^{-14}$	$< 2.7\times10^{-14}$	< 0.21	5.4×10^{-12}	0.26
1543+091	$< 1.4\times10^{-14}$	$< 1.7\times10^{-14}$	2.5×10^{-13}	5.8	3.2×10^{-12}	5.4

*erg cm^{-2} s^{-1}

†1σ upper limits given

**entire galaxy not in IUE aperture

MKN 12 SWP 6723 97 MIN ESSR ONSMTH



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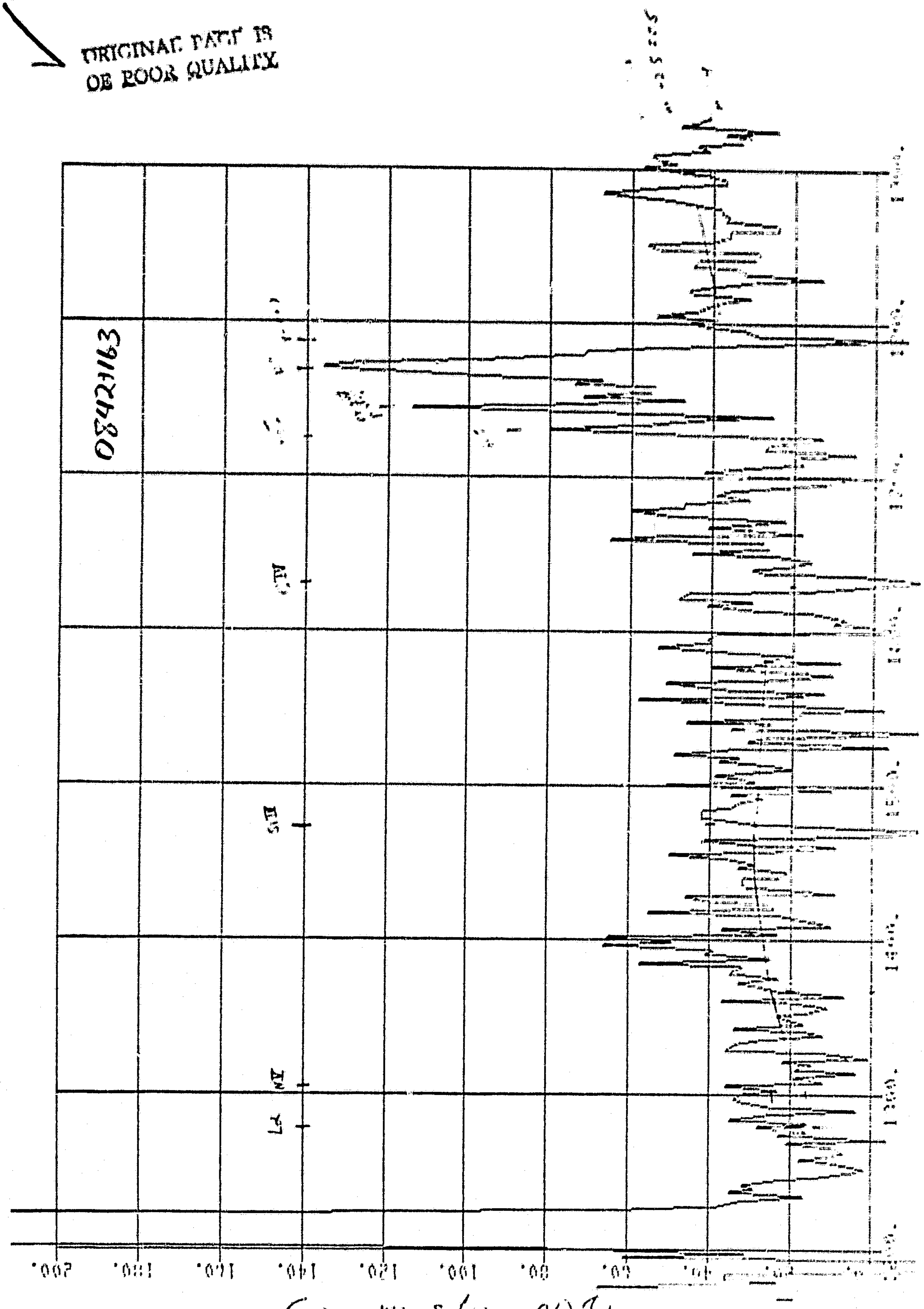

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